Amplified Earthquake Ground-Motion and Surface-Fault-Rupture Hazards for the Smithfield Quadrangle, Central Cache Valley, Utah

by

James P. McCalpin
GEO-HAZ Consulting, Inc.

Barry J. Solomon
Utah Geological Survey

Digital map compilation by James A. McBride
Utah Geological Survey

2001

Research supported by U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 1434-HQ-98-GR-00024. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

UTAH GEOLOGICAL SURVEY

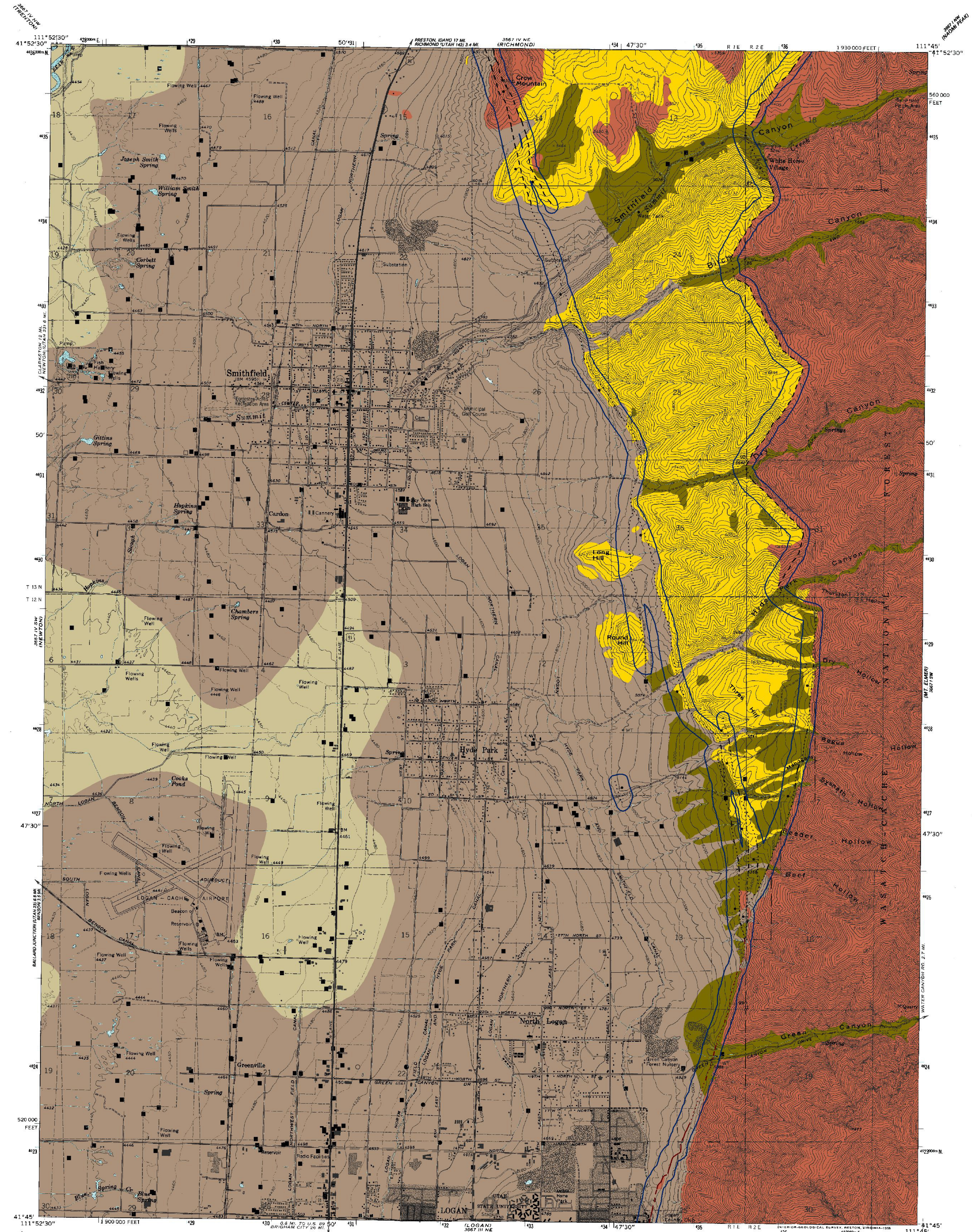
Contour Interval 40 Feet

Scale 1:24,000

1 0 1 2 Miles

5,000 0 5,000 10,000 Feet

1 0 1 2 Kilometers



DISCUSSION

Amplified Ground Motion

Amplification of earthquake ground motion refers to the increase in the intensity of ground shaking that can occur due to local geological conditions, such as the presence of soft soils. Amplified ground motion is one of the most serious causes of earthquake damage. Despite relatively modest ground shaking, the August 30, 1962, earthquake in Cache Valley (magnitude 5.7) caused nearly $1 million of damage (1962 dollars; Lander and Cloud, 1964). This map estimates the amplified ground-motion hazard by: (1) showing the distribution of 1997 Uniform Building Code (UBC), soil-profile types (International Conference of Building Officials, 1997), which correspond to site classes designated by the U.S. National Earthquake Hazards Reduction Program (NEHRP)(Building Seismic Safety Council, 1997) and 2000 International Building Code (IBC)(International Code Council, 1997); (2) applying an example earthquake ground motion (Frankel and others, 1996) to each soil-profile type; and (3) modifying the ground motion with amplification factors (site coefficients) determined by NEHRP to calculate local ground motions. These example ground motions for each mapped soil-profile type are shown in table 1. For actual design ground motions refer to the 1997 UBC, or 2000 IBC if adopted, for appropriate ground motions and site-amplification factors.

This map was compiled by collecting relevant data from geotechnical boreholes, supplementing these data with information from water wells and geologic maps, and integrating data from the three sources into a Geographic Information Systems (GIS) format using ArcView GIS v3.2 (Environmental Systems Research Institute, Inc., 1999) and ArcView Spatial Analyst v2.0a (Environmental Systems Research Institute, Inc., 2000) software. Soil-profile types are defined by shear-wave velocity, undrained shear strength, or standard penetration test (SPT) results in the upper 30 meters of soil or rock. In our four-quadrangle study area, shear-wave velocity was measured in only two locations and undrained shear strength was not measured anywhere. SPT data were measured in 182 geotechnical boreholes, but only eight of the boreholes were drilled to depths of at least 30 meters. In contrast to the limited depth and irregular spatial distribution of geotechnical boreholes, water wells in the central Cache Valley are typically deeper than 30 meters and are widely and uniformly distributed. Of 1,032 water wells in the area, 901 are at least 30 meters deep. Therefore, we use water-well logs to determine the subsurface stratigraphy of the upper 30 meters of soil and geotechnical-boring logs to determine the relationship between SPT data and subsurface stratigraphy. We then estimate SPT values for stratigraphic units in water wells by correlation with Unified Soil Classification System classes in geotechnical boreholes. This link between abundant water-well logs and the correlation between SPT data and subsurface stratigraphy in geotechnical boreholes, supplemented by surficial-geologic map data (McCalpin, 1989; Lowe and Galloway, 1993; Evans and others, 1996; Solomon, 1999), enables us to map soil-profile types.

When using this map, several important qualifiers must be noted:

- Although water wells are more widespread than geotechnical boreholes, geologic interpretations based on water-well logs are less precise than interpretations of borehole logs. The use of water-well logs is appropriate only for regional studies in areas where geotechnical data are sparse or lacking. Water-well logs should not be relied upon for site-specific investigations (table 2).
- Amplification by soft soils diminishes as the strength of ground shaking increases (Building Seismic Safety Council, 1997). Consequently, amplification by soft soils may be less during strong ground shaking generated by a nearby large earthquake, but could be significant for moderate ground shaking generated either by a more distant large earthquake or nearby moderate earthquake. However, moderate ground shaking occurs more frequently than strong ground shaking, so that areas on this map assigned a high amplification factor will be subjected to potentially damaging ground motion more often than areas assigned a low amplification factor.
- This map does not address amplification of ground motion due to resonance. The specific periods of ground motion that match the natural periods of a site can be greatly amplified, and can be particularly destructive to structures whose natural periods match those of the site (Rial and others, 1992).
- This map does not address amplification of ground motion near the fault causing the earthquake due to near-fault rupture directivity. Sites near surface traces of active faults (the West Cache and East Cache fault zones) may be subject to ground motions greater than anticipated. This effect is particularly significant for structures, such as tall buildings, that are sensitive to long-period ground motions (Somerville and others, 1997).
- This map does not address amplification of ground motion due to topography, which can exceed amplification due to soil conditions in some cases. High amplification is commonly experienced on hills, ridges, and the tops of cliffs (Somerville, 1998).
- This map does not address amplification of ground motion due to three-dimensional effects, such as the focusing of energy due to the structure of the earth's crust in the region, which can be as great as amplification due to soil conditions (Somerville, 1998).

Amplified ground-motion hazards on this map reflect variations due to soil conditions, which are applicable to most earthquakes that will affect the region. Near-fault, topographic, and three-dimensional effects are more dependent on the earthquake location and direction of seismic-energy propagation.

Surface Fault Rupture

During a large earthquake, fault rupture at depth may propagate upward and displace the ground surface, forming a main scarp and adjacent zone of deformation. The zone of deformation includes features such as ground cracks and tilted and downdropped blocks. Faults that show evidence of repeated surface displacement during Quaternary (the last 1.6 million years), particularly Holocene (the last 10,000 years), time represent a potential hazard to development. Two fault zones in the central Cache Valley, the West Cache and East Cache fault zones, show clear evidence of Holocene displacement. The Wellsville fault, part of the West Cache fault zone, bounds the west side of the valley in the Wellsville quadrangle (refer to the index map for quadrangle locations). The most recent surface-faulting event on the Wellsville fault occurred between 4,400 and 4,800 years ago (Black and others, 2000). The Junction Hills fault, also part of the West Cache fault zone, extends into the western margin of the Newton quadrangle. The most recent surface-faulting event on the Junction Hills fault occurred between 8,250 and 8,650 years ago (Black and others, 2000). The central segment of the East Cache fault zone bounds the east side of the valley in the Logan and southern Smithfield quadrangles. The most recent surface-faulting event on the central segment occurred about 4,000 years ago (McCalpin, 1994). The northern and southern segments of the East Cache fault zone bound the east side of the valley, respectively, in the northern Smithfield quadrangle and on the southern edge of the Logan quadrangle. Although the northern and southern segments show evidence of Quaternary displacement, the most recent surface faulting occurred on the northern segment at least 15,000 years ago and on the southern segment between 26,000 and 46,000 years ago (McCalpin, 1994).

This map shows faults with evidence of Quaternary surface displacement and special-study areas associated with these faults. The special-study areas, extending 150 meters on the downthrown side and 75 meters on the upthrown side from mapped fault traces, show areas within which site-specific studies should be performed prior to development to evaluate earthquake history, characterize the zone of deformation, and determine fault setbacks.

REFERENCES

Black, B.D., Giraud, R.E., and Mayes, B.H., 2000, Paleoseismic investigation of the Clarkston, Junction Hills, and Wellsville faults, West Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 98, 23 p.

Building Seismic Safety Council, 1997, NEHRP recommended provisions for seismic regulations for new buildings and other structures: Washington, D.C., Federal Emergency Management Agency Publication 302, Part 1 - Provisions, 337 p.

Environmental Systems Research Institute, Inc., 1999, ArcView GIS v3.2: Redlands, California, Environmental Systems Research Institute, Inc.

---2000, ArcView Spatial Analyst v2.0a: Redlands, California, Environmental Systems Research Institute, Inc.

Evans, J.P., McCalpin, J.P., and Holmes, D.C., 1996, Geologic map of the Logan 7.5′ quadrangle, Cache County, Utah: Utah Geological Survey Miscellaneous Publication 96-1, scale 1:24,000, 16 p.

Frankel, Arthur, Mueller, Charles, Barnhard, Theodore, Perkins, David, Leyendecker, E.V., Dickman, Nancy, Hanson, Stanley, and Hopper, Margaret, 1996, National seismic-hazard maps--documentation June 1996: U.S. Geological Survey Open-File Report 96-532, 110 p.

International Code Council, 1997, International Building Code 2000--First Draft: Birmingham, Alabama, 35 chapters.

International Conference of Building Officials, 1997, Uniform Building Code; Volume 2: Whittier, California, 492 p.

Lander, J.F., and Cloud, W.K., 1964, United States earthquakes, 1962: Washington, D.C., U.S. Department of Commerce, Coast and Geodetic Survey, United States Earthquake Series, p. 112-113.

Lowe, Mike, and Galloway, C.L., 1993, Provisional geologic map of the Smithfield quadrangle, Cache County, Utah: Utah Geological Survey Map 143, scale 1:24,000, 18 p.

McCalpin, James, 1989, Surficial geologic map of the East Cache fault zone, Cache County, Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF-2107, scale 1:50,000.

---1994, Neotectonic deformation along the East Cache fault zone, Cache County, Utah: Utah Geological Survey Special Study 83, 37 p.

Rial, J.A., Saltzman, N.G., and Ling, H., 1992, Earthquake-induced resonance in sedimentary basins: American Scientist, v. 80, p. 566-578.

Solomon, B.J., 1999, Surficial geologic map of the West Cache fault zone and nearby faults, Box Elder and Cache Counties, Utah: Utah Geological Survey Map 172, scale 1:50,000, 20 p.

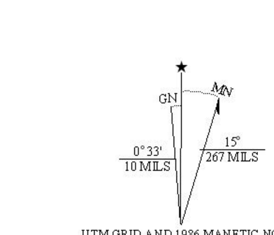
Somerville, P.G., 1998, Emerging art–earthquake ground motion *in* Dakoulas, P., Yegian, M., and Holtz, R.D., editors, Geotechnical earthquake engineering and soil dynamics III: American Society of Civil Engineers, Geotechnical Special Publication 75, p. 1-38.

Somerville, P.G., Smith, N.F., Graves, R.W., and Abrahamson, N.A., 1997, Modification of empirical strong ground motion attenuation relations to include the amplitude and duration effects of rupture directivity: Seismological Research Letters, v. 68, no. 1, p. 199-222.

Table 1. Ground motions and characteristics of UBC soil-profile types in the central Cache Valley, Utah.

Soil-Profile Type (Site class)	Ground Motion: Short Period (0.3 seconds) (typically affecting short buildings[1]) — Spectral Acceleration (g)[2]	Amplification Factor[3]	Local Acceleration (g)[5]	Ground Motion: Long Period (1 second) (typically affecting tall buildings[1]) — Spectral Acceleration (g)[2]	Amplification Factor[4]	Local Acceleration (g)[5]	Characteristics: Standard Penetration Test (blows/ft)[6]	Geology
S_A	1.02	0.8	0.8	0.32	0.8	0.3	n.a.	Hard rock–includes all Paleozoic and Precambrian bedrock units; strongly indurated.
S_B	1.02	1.0	1.0	0.32	1.0	0.3	n.a.	Rock–includes all Tertiary units; weakly indurated.
S_C	1.02	1.0	1.0	0.32	1.5	0.5	>50	Very dense soil–generally coarse-grained deposits with gravel, cobbles, or boulders; includes alluvium and alluvial-fan deposits of major canyons and local areas of shallow bedrock near the range front, but does not necessarily conform to boundaries of geologic units.
S_D	1.02	1.1	1.1	0.32	1.8	0.6	15<N<50	Stiff soil–includes clays of the Bonneville and Little Valley lake cycles and coarser deposits of interpluvial alluvial fans from major drainages
S_E	1.02	0.9	0.9	0.32	2.8	0.9	<15	Soft soil-includes lake clays beyond the distal edges of the pre-Bonneville buried fan gravels.
S_F	Site-specific geotechnical investigation and dynamic site-response analysis shall be performed[7]						Not mapped, but may locally occur.	

[1] The critical period of ground motion for a specific building or building type should be determined by a qualified structural engineer.
[2] Maximum considered earthquake spectral-response accelerations mapped by Frankel and others (1996) based on acceleration at center of four quadrangle study area with 2% probability of exceedance in 50 years, used in IBC and NEHRP provisions. The UBC uses seismic zone factors based on peak accelerations with a 10% probability of exceedence in 50 years.
[3] Acceleration-based site coefficient from NEHRP recommended provisions (Building Seismic Safety Council, 1997, tab. 4.1.2.4a).
[4] Velocity-based site coefficient from NEHRP recommended provisions (Building Seismic Safety Council, 1997, tab. 4.1.2.4b).
[5] Local Acceleration = Spectral Acceleration x Amplification Factor.
[6] Standard Penetration Test (blows/foot) in geotechnical borings or equivalent value predicted for water wells. Range of values for soil-profile types S_C, S_D, and S_E are specified by the Uniform Building Code (International Conference of Building Officials, 1997). n.a.-not applicable
[7] International Conference of Building Officials (1997). Soils requiring site-specific evaluations include soils vulnerable to potential failure or collapse during earthquake ground shaking such as liquefiable soils (shown on plate 2 of this report), quick and highly sensitive clays, and collapsible weakly cemented soils; peats and highly organic clays thicker than 3 meters; very high plasticity clays thicker than 8 meters; and very thick soft/medium stiff clays thicker than 36 meters.

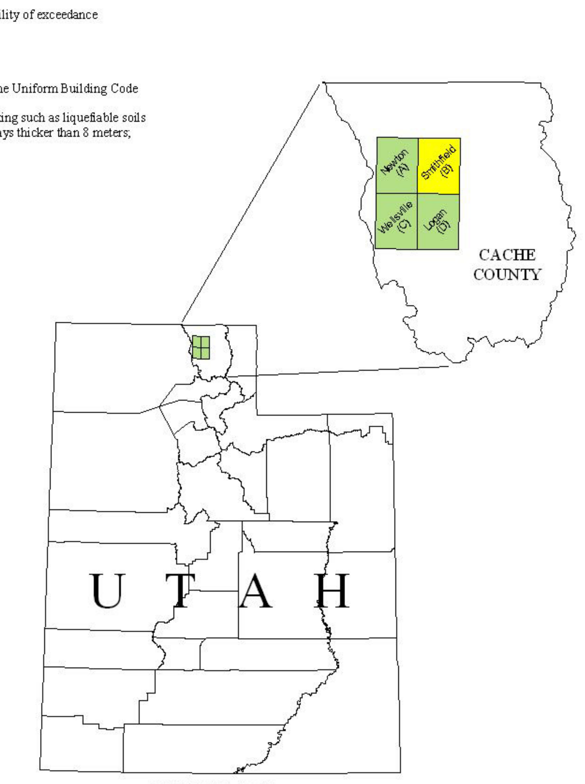


UTM GRID AND 1996 MAGNETIC NORTH DECLINATION AT CENTER OF QUADRANGLE

Table 2. Recommended requirements for site-specific investigations of mapped potential hazards.

Hazard	Soil Profile Type, Special-Study Area, or Potential-Hazard Area		Development Type: Essential Facilities, Special- and High-Occupancy Buildings	Industrial and Commercial Buildings (Other Than High-Occupancy)	Residential Subdivisions	Residential Single Lots
Amplified Ground Motion (Plate 1)	S_A, S_B		No	No	No	No
	S_C, S_D, S_E		Yes	Yes	No	No
	S_F		Yes	Yes	Yes	Yes
Surface Fault Rupture (Plate 1)	Inside Special-Study Area	Holocene Fault	Yes	Yes	Yes	Yes
		Quaternary Fault	Yes	No[1]	No[1]	No[1]
	Outside Special Study Area		Yes	No	No	No
Liquefaction (Plate 2)	High, Moderate		Yes	Yes	No[2]	No[2]
	Low, Very Low		Yes	No	No	No
	Not Susceptible		No	No	No	No
Slope Failure[3] (Plate 3)	Very High, High, Moderate		Yes	Yes	Yes	Yes
	Low, Very Low		Yes	No	No	No

[1] At a minimum, appropriate disclosure should be required.
[2] At a minimum, appropriate disclosure should be required. If a site is also within an area with high or moderate potential for lateral spreading (earthquake-induced slope failure caused by liquefaction on shallow slopes; see plate 3), a site-specific investigation is advised consistent with recommendations for slope-failure hazards.
[3] If permanent cuts have slopes steeper than 2H:1V (50 percent) and are not supported by retaining walls, cut slope stability must be addressed in accordance with the Uniform Building Code (International Conference of Building Officials, 1997, Appendix Chapter 33, section 3312).



INDEX MAP

Sources of Subsurface Data

- ● Geotechnical borehole with data to 30-meter depth
- ○ Geotechnical borehole with insufficient data to classify
- ■ Water well with data to 30-meter depth
- □ Water well with insufficient data to classify
- Shallow excavation (generally less than 3 meters deep) with insufficient data to classify

Fault Symbols

- Holocene fault
- Quaternary fault (with no evidence of Holocene movement)
  Dashed where approximately located, dotted where concealed, ball on downthrown side
- Surface-fault-rupture special-study area

This map is intended primarily for regional planning purposes and should not be used as a substitute for site-specific geotechnical investigations conducted by qualified professionals. The map is not intended for use at scales other than the published scale. Map boundaries are based on limited data available prior to the date of publication, are approximate, and are subject to change as the quantity and quality of available data improve. The hazards at any particular site may actually be higher or lower than shown because of geological variations within a soil-profile type, gradational and approximate map boundaries, and the regional scale of this map.

During an earthquake, ground shaking may occur throughout the map area. The ground-shaking hazard in some areas may not be increased by ground-motion amplification, but location within such areas should not be interpreted as indicating the absence of earthquake ground shaking.

Maps in this report:

- Amplified Ground-Motion and Surface-Fault-Rupture Hazards (Plates 1A-1D)
- Liquefaction Hazards (Plates 2A-2D)
- Susceptibility to Earthquake-Induced Slope Failure (Plates 3A-3D)